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Canopy leaching of subtropical mixed forests under acid rain

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Abstract Leaching of major ions from acid precipitation in a subtropical forest was examined based on an experiment in four sample sites in Shaoshan City, Hunan Province, China, from January 2001 to June 2002. Results clearly show that when rain passed through the canopy, pH increased and the evidence of ion uptake was presented for SO_4^{2-} , NO_3^- , Mg^{2+} and NH_4^+ ions, especially of NH_4^+ and NO_3^- . The percentages of dissolved SO_4^{2-} , Ca^{2+} and Mg^{2+} show a decreasing trend with increasing rainfall. Percentages of leaching Ca^{2+} , K^+ and Cl^- ions show an increasing trend as a function of increased pH values. The forest canopy in Shaoshan City has a strong effect on the uptake of SO_4^{2-} and NO_3^- ions under acid rain conditions. The decreasing order of ions leaching in the forest canopy is as follows: $\text{K}^+ > \text{Ca}^{2+} > \text{Cl}^- > \text{Mg}^{2+} > \text{SO}_4^{2-} > \text{NO}_3^- > \text{NH}_4^+ > \text{Na}^+$.

Keywords acid deposition, leaching and uptake, subtropical forest, Shaoshan City

1 Introduction

The effect of acid rain on forest ecosystems in the world has been well documented over the last quarter century. There are many reports on the characteristics of ion distribution in acid rain, the effect of acid rain on growth and productivity of forests, on soils and simulation of acid rain, etc. (Gao and Cao, 1987; Zhou and Qing, 1992; Draaijers et al., 1994; Draaijers and Erisman, 1995;

Kohno, 1995; Hamburg and Lin, 1998; Feng, 1999). Some studies on the chemical composition, ion concentration and the characteristic distribution of acidity of acid rain in Hunan Province have been carried out (Hanson and Lindberg, 1991; Chen et al., 1997; Fan et al., 1999; Fan and Hong, 2001), but nothing on the leaching of acid rain through the canopy. In our investigation, we have tried to fill this lacuna based on monitoring rainfall data in Shaoshan City from January 2001 to June 2002.

2 Study area

Our study area was located in Shaoshan City ($27^\circ 55' - 27^\circ 56' \text{N}$, $112^\circ 26' - 112^\circ 30' \text{E}$) in central Hunan Province, at an elevation of 292 m, with a subtropical climate, an annual rainfall between 1200 and 1700 mm mostly in the summer and a mean annual temperature of 16.8°C . Vegetation in the area is in the form of a subtropical mixed broadleaf-conifer forest, but largely conifer forests. The trees include *Pinus massoniana*, *Cunninghamia lanceolata*, *Cinnamomum camphora*, *Vernicia fordii* and *Phyllostachys pubescens*. Shrub species include *Camellia japonica*, *Camellia oleifera*, *Nerium indicum*, and *Euonumus japhonicus*. The canopy structure is clearly formed by a number of dominant and co-dominant tree species. Rainfall passes through the canopy to the surface and into the soil. The height of the tree canopy ranges from 10 to 30 m and that of the shrubs from 0.8 to 3.5 m. The soil is a soft yellow and yellow brown soil.

3 Methods

3.1 Sampling

We located 32 sampling points in four sampling areas ($30 \text{ m} \times 30 \text{ m}$) in an open zone around the forest from January 2001 to June 2002. Rainfall was sampled automatically with a rain gauge (Sweden), special barrel of polythene. After deciding on the principal tree, at one-meter above the ground, a polythene collector with a diameter of 10 cm was fixed on it. A special polythene

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container was fastened under the collector to measure the canopy throughfall, with a filter placed between the collector and the container to prevent leaves and insects from falling into the container. Another open polythene container, with a diameter of 15 cm, was fixed in the soil to collect ground throughfall. Rainfall, canopy throughfall and ground throughfall were sampled once a week.

3.2 Methods

Samples were measured immediately by a numeric acidometer (PHS-3C) for pH and then sent to the laboratory for measurement of K⁺, Ca²⁺, Mg²⁺, Na⁺ and Al³⁺ ions contents by an atomic absorption spectrophotometer (SH-3800, Hitachi Company) and SO₄²⁻, NO₃⁻, F⁻, Cl⁻ and NH₄⁺ by an ion chromatograph (DX-120, Dionex Company).

4 Results and analysis

4.1 Variation of rainfall pH

As shown in Table 1, the pH value of rainfall clearly increased after passing through the canopy and ground vegetation. Presumably, the positive base ions (Ca²⁺, Mg²⁺, K⁺, Mn²⁺, etc.) in the canopy had an exchangeable reaction with H⁺ in the rain where H⁺ replaced the base ions to decrease the amount of H⁺ in the rainfall and increased the pH value. On the other hand, the maximum incremental value of pH in bulk precipitation occurred in the spring (March to June). The values of the pH increased by 2.24 and 2.27 units, respectively, after passing through the

canopy and ground vegetation, representing percentage increases of 51.5% and 52.2% over those of 2001. It indicates that the base ions in leaves were more active and obviously most leaching events occurred during the growing season of the spring.

4.2 Canopy leaching

4.2.1 Effects of canopy ions absorbing from atmospheric precipitation

As seen in Fig. 1, the percentages of SO₄²⁻, NO₃⁻, Mg²⁺, NH₄⁺ and Na⁺ leaching from atmospheric precipitation had some negative values. This indicates that subtropical mixed broadleaf-conifer forests can absorb these ions, especially the NH₄⁺ and Na⁺ ions. In 2002, the percentage of leached NH₄⁺ and Na⁺ ions was -66% and -108% in the spring and -65% and -37% during the summer. There were similar observations in 2001. Some studies suggest that the amount of H⁺, NO₃⁻ and NH₄⁺ ions in atmospheric precipitation could decrease by 50% to 70% by canopy uptaking during the growing season and that the amounts of nutrition ions, such as Ca²⁺, Mg²⁺ and K⁺ increased by canopy leaching (Galloway and Likens, 1976; Gay and Murph, 1985; Mahendrappa, 1991). In our study, the canopy had clearly taken up NH₄⁺, Na⁺, SO₄²⁻ and NO₃⁻ ions during the growing season, especially NH₄⁺ and Na⁺ ions.

4.2.2 Changes in ion leaching by rainfall

As seen in Fig. 1, the percentages of leached SO₄²⁻, Ca²⁺ and Mg²⁺ ions show a clear trend of reduction with

Table 1 Average quarterly monitoring values over time

| year | month | precipitation/mm | item | pH value | ion concentration/mg·L ⁻¹ | | | | | | | |
|------|-------|------------------|------|----------|--------------------------------------|------------------------------|------------------|------------------|------------------------------|-----------------|----------------|-----------------|
| | | | | | SO ₄ ²⁻ | NO ₃ ⁻ | Ca ²⁺ | Mg ²⁺ | NH ₄ ⁺ | Na ⁺ | K ⁺ | Cl ⁻ |
| 2001 | 1-3 | 220 | BK | 4.75 | 3.07 | 1.49 | 1.31 | 0.23 | 3.89 | 0.28 | 0.53 | 0.63 |
| | | | TF | 5.96 | 6.20 | 1.25 | 9.50 | 0.60 | 5.62 | 0.26 | 3.12 | 2.10 |
| | | | GF | 7.02 | 6.60 | 1.10 | 11.40 | 0.70 | 2.20 | 0.50 | 2.00 | 2.50 |
| 2001 | 3-6 | 250 | BK | 4.35 | 1.20 | 0.10 | 3.50 | 0.45 | 1.20 | 0.36 | 0.29 | 2.03 |
| | | | TF | 6.59 | 4.40 | 0.71 | 6.64 | 0.80 | 3.43 | 0.28 | 3.16 | 2.84 |
| | | | GF | 6.89 | 3.50 | 0.31 | 9.70 | 0.10 | 1.81 | 0.33 | 2.73 | 2.35 |
| 2001 | 6-9 | 288 | BK | 5.51 | 1.21 | 0.43 | 1.01 | 0.18 | 0.55 | 0.16 | 0.22 | 0.24 |
| | | | TF | 6.18 | 4.64 | 1.72 | 4.90 | 0.76 | 3.13 | 0.64 | 4.80 | 2.18 |
| | | | GF | 6.11 | 6.10 | 2.45 | 5.52 | 1.29 | 5.13 | 0.76 | 7.54 | 4.74 |
| 2001 | 9-12 | 340 | BK | 4.30 | 2.80 | 0.80 | 0.90 | 0.10 | 1.90 | 0.30 | 0.50 | 0.60 |
| | | | TF | 4.32 | 9.60 | 2.20 | 7.10 | 1.30 | 2.40 | 0.59 | 5.90 | 4.90 |
| | | | GF | 4.72 | 12.90 | 2.50 | 9.10 | 1.80 | 2.50 | 0.60 | 4.70 | 4.70 |
| 2002 | 1-3 | 520 | BK | 4.25 | 8.32 | 1.39 | 6.37 | 0.98 | 2.72 | 1.15 | 0.90 | 1.94 |
| | | | TF | 4.43 | 12.83 | 3.37 | 10.35 | 1.45 | 2.58 | 0.70 | 4.40 | 3.02 |
| | | | GF | 4.60 | 12.73 | 3.17 | 9.36 | 1.29 | 2.61 | 0.60 | 3.50 | 2.83 |
| 2002 | 3-6 | 880 | BK | 4.51 | 2.54 | 0.78 | 1.30 | 0.30 | 1.29 | 0.30 | 0.30 | 0.46 |
| | | | TF | 5.76 | 2.40 | 0.68 | 2.20 | 0.40 | 1.25 | 0.35 | 1.60 | 1.55 |
| | | | GF | 5.81 | 3.85 | 0.88 | 2.80 | 0.50 | 1.59 | 0.20 | 2.20 | 0.09 |

Note: BK is bulk precipitation; TF: throughfall; GF: ground throughfall.

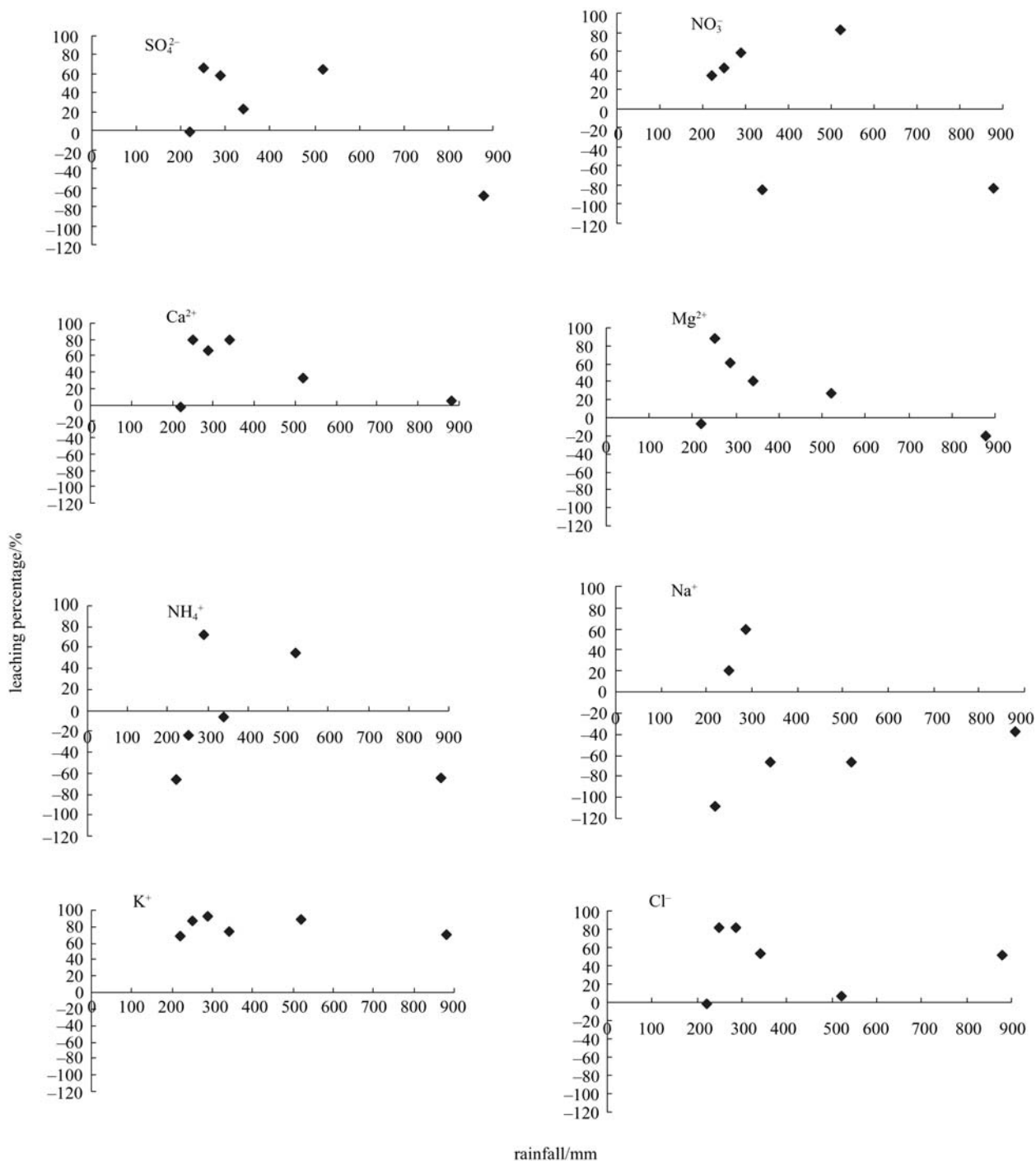


Fig. 1 Change of leaching percentage of major ions as a function of rainfall

increasing rainfall. The reason for the reduction of leached SO_4^{2-} could be that the rainfall was acidic with relatively large amounts of SO_4^{2-} and NO_3^- so that the forest canopy absorbed some SO_4^{2-} ions. The reason for the reduction in Ca^{2+} and Mg^{2+} could be that the most Ca^{2+} and Mg^{2+} ions came from the dust of the ground. The dusts on the canopy were washed out by the rainfall, and the amounts of Ca^{2+} and Mg^{2+} ions were diluted by the abundant rainfall, so the percentage of

leached ions was reduced with increasing rainfall. The percentage of leached K^+ ions remained high regardless of the amount of rainfall. Perhaps the K^+ ions are very active.

4.3 Change of leaching as a function of pH

As shown in Table 2, the percentages of leached Ca^{2+} , K^+ and Cl^- ions show an increasing trend as a function of pH.

Table 2 Effects of pH in rainfall on ions leaching through canopies

| pH | ion concentration in rainfall/mg·L ⁻¹ | | | | | leaching percentage/% | | | | | | |
|---------|--|------|-------------------------------|------------------------------|-------------------------------|------------------------------|------------------|------------------|------------------------------|-----------------|----------------|-----------------|
| | range | mean | SO ₄ ²⁻ | NO ₃ ⁻ | SO ₄ ²⁻ | NO ₃ ⁻ | Ca ²⁺ | Mg ²⁺ | NH ₄ ⁺ | Na ⁺ | K ⁺ | Cl ⁻ |
| 4.0-4.5 | | 4.30 | 4.11 | 0.76 | 43.20 | 53.33 | 37.13 | 36.15 | -11.60 | -51.45 | 70.86 | 28.99 |
| 4.5-5.0 | | 4.68 | 2.81 | 1.14 | -22.93 | -83.59 | 42.08 | 10.46 | -36.04 | -51.86 | 71.91 | 53.07 |
| 5.0-5.5 | | 5.51 | 1.21 | 0.43 | 58.32 | 59.03 | 67.00 | 61.90 | 72.00 | 60.17 | 92.71 | 82.50 |

We can conclude that acid rain decreases the percentage of leached Ca²⁺, K⁺ and Cl⁻ ions in the ecological system of the forest. As shown in Table 1, the forest canopy has its strongest effect on the uptake of SO₄²⁻ and NO₃⁻ ions under long-term conditions of acid rain. The percentages of leached ions were -22.93% and -83.89%. So the forest has an important buffer function in soil acidification. When the pH is in the range of 4.5 to 5.0, the forest canopy has a clear uptake function of NH₄⁺ and Na⁺ ions. It could be that the canopy absorbed these increased amounts of ions.

4.4 Analysis of order of leaching

The ion concentrations of atmospheric precipitation and throughfall, calculated from the percentage of ions deposited by rainfall and throughfall in the 18 months by the rainfall, are shown in Table 3. Only the percentage of leached Na⁺ ion was negative during these 18 months. The forest canopy had a strong uptake only of Na⁺ and clearly no uptake of any of other ions. Ions leaching in the forest canopy declined in the following order: K⁺ > Ca²⁺ > Cl⁻ > Mg²⁺ > SO₄²⁻ > NO₃⁻ > NH₄⁺ > Na⁺.

5 Conclusions and discussion

5.1 Conclusions

The pH values of atmospheric precipitation clearly increased after passing through the canopy and the ground vegetation. The greatest increase occurred during an event of 520 mm rainfall.

The percentages of leached ions from atmospheric precipitation included some negative values. The subtropical mixed broadleaf-conifer forest could absorb SO₄²⁻, NO₃⁻, Mg²⁺ and NH₄⁺ ions, especially NH₄⁺ and NO₃⁻ ions.

The percentages of leached SO₄²⁻, Ca²⁺ and Mg²⁺ ions clearly show a reduction with the increase in rainfall.

The percentages of leached Ca²⁺, K⁺ and Cl⁻ show an increasing trend as a function of pH.

The forest canopy in Shaoshan City has a strong effect on the uptake of SO₄²⁻ and NO₃⁻ ions when subjected to acid rain over long period. The percentages of leached ions are increasing.

The decreasing order of ion leaching in the forest canopy in Shaoshan City is as follows: K⁺ > Ca²⁺ > Cl⁻ > Mg²⁺ > SO₄²⁻ > NO₃⁻ > NH₄⁺ > Na⁺.

5.2 Discussion

We studied the changes in concentrations of ions in atmospheric precipitation passing through the forest canopy and ground vegetation. In the first instance, we investigated the process of the change in the chemical characteristics of atmospheric precipitation and analyzed the reason for these changes in the amount of ions. It is important to point out that this study only investigated wet sedimentation in the acid sedimentation. In the future, both wet and dry sedimentations must be considered together. On the other hand, the effect of the atmospheric precipitation after the forest canopy to the forest soil should be the major emphasis in the next study.

Table 3 Changes of leaching ions in the forest of Shaoshan City

| item | ions of canopy leaching | | | | | | | |
|--|--|------------------------------|------------------|------------------|------------------------------|-----------------|----------------|-----------------|
| | SO ₄ ²⁻ | NO ₃ ⁻ | Ca ²⁺ | Mg ²⁺ | NH ₄ ⁺ | Na ⁺ | K ⁺ | Cl ⁻ |
| ionic concentration of rainfall/mg·L ⁻¹ | 3.19 | 0.83 | 2.38 | 0.37 | 1.93 | 0.43 | 0.46 | 0.98 |
| ionic concentration of throughfall/mg·L ⁻¹ | 6.68 | 1.66 | 6.78 | 0.89 | 3.07 | 0.47 | 3.83 | 2.77 |
| depositing percentage of ions in rainfall/kg·hm ⁻² ·year ⁻¹ | 44.60 | 11.60 | 33.27 | 5.17 | 26.98 | 6.01 | 6.43 | 13.70 |
| depositing percentage of ions in throughfall/kg·hm ⁻² ·year ⁻¹ | 64.13 | 15.94 | 65.09 | 8.54 | 29.47 | 4.51 | 36.77 | 26.59 |
| net canopy leaching/kg·hm ⁻² ·year ⁻¹ | 19.53 | 4.34 | 31.82 | 3.37 | 2.49 | -1.50 | 30.34 | 12.89 |
| leaching percentage/% | 30.45 | 27.20 | 48.88 | 39.51 | 8.46 | -33.22 | 82.51 | 48.48 |
| leaching sequence | K ⁺ > Ca ²⁺ > Cl ⁻ > Mg ²⁺ > SO ₄ ²⁻ > NO ₃ ⁻ > NH ₄ ⁺ > Na ⁺ | | | | | | | |

Note: Annual rainfall is 1398 mm, annual throughfall 960 mm.

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